

(19) World Intellectual Property Organization  
International Bureau



(43) International Publication Date  
25 January 2007 (25.01.2007)

PCT

(10) International Publication Number  
**WO 2007/010299 A1**

(51) International Patent Classification:  
C07C 29/132 (2006.01) C07C 31/20 (2006.01)  
C07C 31/10 (2006.01)

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(21) International Application Number:  
PCT/GB2006/050181

(81) Designated States (unless otherwise indicated, for every  
kind of national protection available): AE, AG, AL, AM,  
AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN,  
CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI,  
GB, GD, GE, GH, GM, HN, HR, HU, ID, IL, IN, IS, JP,  
KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT,  
LU, LV, LY, MA, MD, MG, MK, MN, MW, MX, MZ, NA,  
NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC,  
SD, SE, SG, SK, SL, SM, SY, TJ, TM, TN, TR, TT, TZ,  
UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(22) International Filing Date: 30 June 2006 (30.06.2006)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:  
0514593.3 15 July 2005 (15.07.2005) GB

(84) Designated States (unless otherwise indicated, for every  
kind of regional protection available): ARIPO (BW, GH,  
GM, KE, LS, MW, MZ, NA, SD, SI, SZ, TZ, UG, ZM,  
ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM),  
European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI,  
FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, NL, PL, PT,  
RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA,  
GN, GQ, GW, ML, MR, NE, SN, TD, TG).

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Published:

— with international search report

For two-letter codes and other abbreviations, refer to the "Guid-  
ance Notes on Codes and Abbreviations" appearing at the begin-  
ning of each regular issue of the PCT Gazette.

(54) Title: PROCESS

(57) Abstract: A process for hydrogenation of glycerol in which a feed comprising glycerol is contacted with a stream of a hydro-  
gen-containing gas and subjected to hydrogenation in the vapour phase in the presence of a catalyst at a temperature of from about  
160°C to about 260°C, a pressure of from about 10 to about 30 bar, a hydrogen to glycerol ratio of from 400: 1 to about 600: 1 and  
a residence time of from about 0.01 to about 2.5 hr.

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## VAPOUR-PHASE HYDROGENATION OF GLYCEROL

The present invention relates to a process for the hydrogenation of 1,2,3-propanetriol, also known as glycerol, in the vapour phase. More particularly it relates to the selective hydrogenation of glycerol in the vapour phase whereby alteration of the process conditions enables selection of 1,2-propanediol or propanols as the major product.

Glycerol is available in large quantities and it is anticipated that the supply of glycerol will increase as it is a by-product of processes which are becoming increasingly attractive since they are based on natural products such as oils and fats as starting materials. Examples of oils and fats include palm oil, rape seed oil, beef tallow and the like.

However, whilst glycerol is available in large quantities its present uses are limited in volume. It is therefore desirable to provide processes which enable the glycerol to be converted to useful materials. It will therefore be understood coupling downstream processes which use glycerol as a feedstock to processes which have glycerol as a by-product offers economic advantages. Thus processes to which a glycerol reactor could be coupled include bio-diesel units and fat splitters such as feed units to natural detergent plants and the like.

Although glycerol does not have uses to match its availability, it can be converted to 1,2-propanediol and 2-propanol which are valuable starting materials which have various applications. Various processes have been proposed for effecting the conversion.

In US 5426249, which is incorporated herein by reference, there is described a process in which a gaseous stream of glycerol is dehydrated to acrolein. The acrolein is then condensed and hydrated to 3-hydroxypropionaldehyde which is then subjected to hydrogenation in the liquid phase. This multi-step process enables 1,2- and 1,3-propanediol to be obtained simultaneously.

US5214219, which is incorporated herein by reference, describes a process in which glycerol is converted to 1,2-propanediol and 1,2-ethanediol. In this process hydrogenation of the glycerol is carried out in the liquid phase in the presence of a copper/zinc catalyst and at a temperature of about 220°C.

An alternative processes for the liquid phase hydrogenation of glycerol is described in US5616817, which is incorporated herein by reference. The process, which is directed to the production of 1,2-propanediol, requires the glycerol to have a water content of no more than 20% by weight. The hydrogenation is carried out in the presence of a catalyst comprising cobalt, copper, manganese and molybdenum.

Chaminand *et al.* Green Chem. 6, (2004) 359-361 describes a process in which the glycerol is hydrogenated in the liquid phase using a supported metal catalyst. At the process conditions of 180°C and 85 bar the reaction rate is slow with only 20% conversion being achieved after 168 hours.

An alternative process is described in Desari *et al* Catalysis A281, (2005) 225-231 in which a copper/chrome catalyst is used for the liquid phase hydrogenation of glycerol. However, conversion was low with conversion rates of less than 30% being noted. It is suggested that this is due to the catalyst becoming deactivated and reactivation of the catalyst between tests was required.

DE4302464 and DE524101 describe in detail liquid phase processes for the production of 1,2-propanediol from glycerol. Whilst each makes passing reference to the possibility of the production being carried out in the vapour phase, neither document describes how the process can be efficiently and commercially carried out in the vapour phase to obtain high conversion and selectivity.

Whilst the processes described above offer means for obtaining desirable products from glycerol, they suffer from various disadvantages and drawbacks in terms of conversion, rate and/or economics and it is therefore desirable to provide alternative, and preferably improved, processes.

It has now been discovered that glycerol can be efficiently converted to the desired products by means of a hydrogenation reaction carried out in the vapour phase.

Thus according to one aspect of the present invention there is provided a process for

hydrogenation of glycerol in which a feed comprising glycerol is contacted with a stream of a hydrogen-containing gas and subjected to hydrogenation in the vapour phase in the presence of a catalyst at a temperature of from about 160°C to about 260°C, a pressure of from about 10 to about 30 bar, a hydrogen to glycerol ratio of from 400:1 to about 600:1 and a residence time of  
5 from about 0.01 to about 2.5 secs.

It is surprising that it has been possible to carry out the hydrogenation reaction in the vapour phase since it has generally been believed that this was not possible due to the high boiling point of the glycerol. The requirement to use high temperatures would be anticipated to cause the  
10 glycerol to coke leading to operating problems. The high operating temperatures would also be expected to adversely affect the catalyst.

However, it has now been found that using the conditions of a temperature of from about 160°C to about 260°C, a pressure of from about 10 to about 30 bar, a hydrogen to glycerol ratio of from  
15 about 400:1 to about 600:1 and a residence time of from about 0.01 to about 2.5 secs enables the expected problems to be obviated. Carrying out the hydrogenation in the vapour phase offers various advantages over prior art liquid phase processes. In general, the residence time in the hydrogenation reactor is less. This is advantageous since short residence times lead to the formation of fewer by-products. The present invention also makes it possible to operate at lower  
20 pressures whilst maintaining high overall selectivities to the desired products.

Any suitable process is used for the hydrogenation reaction. In one arrangement, the glycerol is vaporised into a stream of hydrogen-containing gas in a vaporiser before being passed to a hydrogenation reactor. It will be understood that the vaporiser and the hydrogenation reactor may  
25 be separate or may be zones located in the same reactor. Where a vaporiser is present, the hydrogen rich vapour stream will generally be passed directly to the hydrogenation reactor.

The hydrogen-containing gas stream may be fed to the vaporiser where present or to the hydrogenation reactor at any suitable temperature.

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The hydrogenation-containing gas may include minor amounts of one or more inert gases which may include nitrogen, carbon oxides, neon, argon and/or low molecular weight hydrocarbons

such as methane, ethane, propane, n-butane and iso-butane. Ethanol and ethyl acetate may also be present.

The glycerol feed may be from any source. It may be pure glycerol or it may contain other components such as other organic compounds, water and/or impurities. For example, the glycerol feed may include one or more of water, alcohols such as methanol, ethanol, propanol, hydroxy propanone, butanols and the like and esters. Involatile components may also be present.

Where such components are present, they may be removed from the reaction by means of a purge which is usually taken from the bottom of the vaporiser. The other components present will largely depend on the source of the glycerol. Since the process of the present invention may be carried out in the presence of such components there is no requirement to purify the glycerol prior to it being used as a feedstock. This offers significant advantages when the process of the present invention is to be coupled to plants in which glycerol is formed as a by-product. The process of the present invention will also be able to operate in the presence of a high salt and/or ash content.

Any suitable catalyst system may be used. In a preferred arrangement, the catalyst will be provided as a fixed bed located in the hydrogenation reactor. Any suitable catalyst may be used. In one arrangement, a reduced copper catalyst may be used. Examples include copper/alumina/manganese, copper chromite, copper silica, copper zinc alumina, copper zinc oxide, raney copper and the like. Reduced nickel or reduced cobalt containing catalysts may also be used. Precious metal catalysts such as those containing ruthenium, palladium, platinum, rhodium and/or iridium may be used. These may be supported on, for example, carbon, alumina and silica.

The process may be carried out at any suitable reaction conditions within the ranges of the present invention. Preferred temperatures are from about 200°C to about 240°C. Temperatures of from about 205°C to about 220°C are particularly suitable. Pressures in the range of from about 17 bar to about 23 bar preferred with a pressure of 20 bar being particularly suitable. A residence time of from about 0.3 to about 1.5 secs may be used with a residence time of about 0.5 secs being particularly suitable.

The ratio of hydrogen to glycerol in the hydrogenation reactor feed is a function of temperature and the operating pressure. Preferred hydrogen to glycerol ratio is in the range of from about 450:1 to about 550:1. A ratio of about 500:1 is most preferred.

- 5 Surprisingly the process of the present invention offers excellent conversion. Conversions in excess of 95%, 98% and even in excess of 99% have been noted. However, in the event of incomplete conversion, separation of product from glycerol is readily achieved and unreacted glycerol may be recycled. By-products which may be formed, such as 1-hydroxy propanone, may be recycled for further reaction to the desired product.

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Water will be produced in the reaction and at least a portion of the water produced may be recycled. Thus, other than at start up it is not generally necessary to add water to the glycerol to protect the catalyst which has been a feature of liquid phase reactions.

- 15 In a most preferred embodiment, the present invention relates to the selective hydrogenation of glycerol. In one arrangement, the invention selectively forms 1,2-propanediol and in an alternative arrangement the invention selectively forms propanols.

In general reaction temperatures of less than about 210°C favour the formation of the 1,2-propanediol while those of about 210°C and above favour the formation of propanols.

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The present invention will now be described with reference to the following examples.

#### **Examples 1 to 6**

- 25 A 0.75" reactor was charged with 75 g (50mls) of catalyst DRD 9289 A, a copper based catalyst from Davy Process Technology Ltd, and reduced by conventional means. A feed of glycerol and methanol was fed to a heated vessel with the hydrogen at the reaction pressure and complete vapourisation of the feed mixture. The resultant gaseous stream was then passed to the reactor and contacted with the catalyst. Products removed from the reactor were condensed at 10°C and
- 30 were analysed on a Hewlett Packard HP3560 GC equipped with a micro TCD detector. The conditions for the various examples are set out in Table 1 and the results are set out in Table 2.

Table 1

Example No	1	2	3	4	5	6
Inlet Temperature °C	200	200	195	195	195	195
Pressure, bar	20	20	20	20	20	20
Residence Time, s	0.97	0.45	0.78	0.69	0.35	0.31
Hydrogen:Glycerol ratio	461	477	597	572	595	599
LHSV, Hr <sup>-1</sup>	0.287	0.625	0.303	0.356	0.676	0.755

Table 2

Example	1	2	3	4	5	6
Product Sel, Mol %						
Ethanol	0.77	0.28	1.04	0.81	0.37	0.25
2-Propanol	1.59	0.59	1.87	1.45	0.67	0.47
1-Propanol	1.35	0.54	1.37	1.08	0.53	0.38
Hydroxypropanone	1.41	1.53	1.09	1.19	1.11	1.11
Ethylene Glycol	1.05	1.15	0.65	1.00	1.28	1.24
Propylene Glycol	93.28	95.65	93.71	94.13	95.98	96.51
Others	0.55	0.26	0.27	0.34	0.06	0.05
Conversion	100	97.63	100	100	99.94	99.54



**CLAIMS**

1. A process for hydrogenation of glycerol in which a feed comprising glycerol is contacted with a stream of a hydrogen-containing gas and subjected to hydrogenation in the vapour phase in the presence of a catalyst at a temperature of from about 160°C to about 260°C, a pressure of from about 10 to about 30 bar, a hydrogen to glycerol ratio of from 400:1 to about 600:1 and a residence time of from about 0.01 to about 2.5 hr<sup>-1</sup>.
2. A process according to Claim 1 wherein the glycerol feed is vaporised into a stream of hydrogen-containing gas in a vaporiser before being passed to a hydrogenation reactor.
3. A process according to Claim 1 or Claim 2 wherein the catalyst is provided as a fixed bed located in the hydrogenation reactor.
4. A process according to any one of Claims 1 to 3 wherein the catalyst is a reduced copper catalyst.
5. A process according to any one of Claims 1 to 4 wherein the reaction temperature is from about 200°C to about 240°C.
6. A process according to any one of Claims 1 to 5 wherein the reaction temperature is from about 205°C to about 220°C.
7. A process according to any one of Claims 1 to 6 wherein the reaction pressure is from about 17 bar to about 23 bar.
8. A process according to any one of Claims 1 to 7 wherein the reaction pressure is from about 20 bar.
9. A process according to any one of Claims 1 to 8 wherein the residence time is from about 0.3 secs to about 1.5 secs.

10. A process according to any one of Claims 1 to 8 wherein the residue time is about 0.5 secs.
11. A process according to any one of Claims 1 to 10 wherein the hydrogen to glycerol ratio is from about 450:1 to about 550:1.
12. A process according to any one of Claims 1 to 11 wherein the hydrogen to glycerol ratio is from about 500:1.
13. A process according to any one of Claims 1 to 12 wherein the process is selective for the formation of 1,2-propanediol.
14. A process according to Claim 13 wherein the temperature is less than about 210°C
15. A process according to any one of Claims 1 to 12 wherein the process is selective for the formation of propanols.
16. A process according to Claim 15 wherein the temperature is about 210°C or more.

## INTERNATIONAL SEARCH REPORT

International application No

PCT/GB2006/050181

A. CLASSIFICATION OF SUBJECT MATTER  
 INV. C07C29/132 C07C31/10 C07C31/20

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)  
 C07C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, BEILSTEIN Data, CHEM ABS Data

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	DE 524 101 C (I.G. FARBENINDUSTRIE AKT.-GES) 11 May 1931 (1931-05-11) cited in the application page 1, line 36 - line 39 example 1 page 2, line 36 - line 38; example 3	1
A	DE 43 02 464 A1 (HENKEL KGAA, 40589 DUESSELDORF, DE) 4 August 1994 (1994-08-04) cited in the application page 2, line 21 - line 26 page 2, line 29 - line 51 page 3, line 13 - line 14 example 8	1

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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Date of the actual completion of the international search

12 October 2006

Date of mailing of the international search report

24/10/2006

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# INTERNATIONAL SEARCH REPORT

International application No  
PCT/GB2006/050181

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
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DE 4302464	A1	04-08-1994	NONE	